Approaches to the Evaluation of Fisheries Impacts Under the ESA

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1 Introduction

The ecosystem approach to fisheries management endeavors to achieve the sustainability of ecosystems while maintaining some level of exploitation of fish stocks, within the constraints of uncertainty about natural and human processes (MRAG Americas 2000).

At present, there are several major assumptions involved in the management of fisheries and the science on which that management is based:

- a certain level of removal of targeted fish stocks is tolerable without compromising the ecosystem;
- as long as the target fisheries stay within the limits set by the TAC and other FMP rules and regulations, the fisheries do not cause intolerable harm (for example to listed species); and
- the management and scientific structure is capable of detecting harmful or intolerable effects.

Consideration of the sustainability of non-target species (as opposed to ecosystems) has been the subject of much recent debate, particularly in relation to marine mammals and birds that may be affected indirectly (competition with fisheries for food) or directly (incidental mortality in fishing operations). Fisheries that involve threatened or endangered (listed) species provide a special problem because management of fishing effort involves simultaneous questions concerning obtaining catch from the fishery and recovery of the listed species

We discuss the issues to be considered in applying the ecosystem approach to problems related to listed species, particularly as it relates to the Endangered Species Act. In so doing, we develop

i) a conceptual framework for considering ecosystem issues and the variety of factors that may influence the dynamics of higher level predators,

ii) an approach to thinking about models that can be used to explore the effects of alternative approaches to fisheries management on marine mammals and birds, and

iii) a framework for establishing a monitoring program that could be set in place to assist managers in making decisions about the effects of fishing on the ecosystem and listed species.

Our models are intentionally simple and non-specific to a particular ecosystem, because the goal here is to provide the framework for further detailed applications of these concepts and those elaborated in MRAG Americas (2000).

Of particular relevance in this discussion is the need for a methodology that permits prospective and ongoing evaluation of the consequences of alternative management measures of the rate of recovery of listed species, such that the recovery is not compromised by an unacceptable amount. Such a methodology will lead to the development of a feedback management procedure for adjust fisheries controls according to the information being provided from monitoring. This will be elaborated in the fourth section.

2 Conceptual Framework for Considering Ecosystem Issues

A conceptual framework for considering the ecosystem effects of fishing must focus on three types of effects:

i) incidental mortality of non-target species in fisheries operations;

ii) indirect effects on food webs; and

iii) direct effects on habitat.

2.1 Recommendations of the Ecosystem Advisory Panel

The Ecosystem Advisory Panel (1999) recommends the development of a Fisheries Ecosystem Plan (FEP) that mimics the Fishery Management Plan and which has these components:

1. Delineate the geographic extent of the ecosystem under consideration.

2. Develop a conceptual model of the food web.

3. Describe the habitat needs of different life history stages of the organisms in the “significant food web” and how they are considered in conservation and management measures

4. Calculate total removals -- including incidental mortality -- and show how they relate to standing biomass, production, optimum yields, natural mortality, and trophic structure

5. Assess how uncertainty is characterized and what kind of buffers against uncertainty are included in conservation and management actions.

6. Develop indices of ecosystem health as targets for management

7. Describe available long-term monitoring data and how they are used

8. Assess ecological, human, and institutional elements of the ecosystem that most significantly affect fisheries

The review of ecosystem approaches to fisheries management by MRAG Americas (2000) highlights a number of points in this context.

First, delineating the geographic extent of the ecosystem will include an evaluation of the land-water interface as well as circumscribing the most important spatial relationships amongst species.

Second, developing the conceptual model of the food web can often be done, but may be problematic, because in the marine environment the same individual, at different times in its life plays a different role in the food web (e.g. adult foxes rarely eat baby wolves, but adult anchovy may prey on mackerel eggs and early life stage juveniles). Pitcher and Hart (1982, pg 37) show how herring interact with different members of the plankton, depending upon the age of the individual herring.

In other cases, the sheer numbers of species involved makes creating a food web difficult; for example, more than 35 species are involved in the northwest Atlantic groundfish complex

(Boreman et al 1997, pg xxi; Murawski et al 1997, pg 62-70); the eastern Bering Sea fishery involves more than 15 species of flatfish, 20 of rockfish, and 4 of groundfish, plus squid (Francis et al. 1988, pg 190) One solution, consistent with Fager's notion of communities as recurrent groups, is to focus on species assemblages (eg. Rothschild et al. 1997, pg 148). Another is to draw webs of increasing complexity (Mangel 1988, pg 90-91).

Thus the food web needs to focus on the primary interactions between the fishery and components of the food web and the possible interactions that might provide feedback to the primary interaction (see Yodzis 2000).

Third, in the description of long-term monitoring, an evaluation of habitat condition, oceanographic variability, potential confounding influences (e.g. terrestrial, freshwater, waste disposal) and scales of interactions amongst these factors need to be described and the overall status of the system related to the targets for management.

Fourth, based on the review in MRAG Americas (2000), we propose that the list compiled by the Ecosystem Advisory Panel be expanded to include two more points:

9. Identify the spatial and temporal manifestations of effects

This is required to verify that the assessments, management decisions and future monitoring activities account for the types of effects that might arise and whether the management system is able to respond to these before irreversible changes occur.

10. Establish a prospective evaluation of management procedures (including monitoring, assessment and decision rules) and the implementation of a precautionary approach. Prospective management includes establishing the following (see MRAG Americas (2000) for further details):

    • Objectives for ecosystem, fishery, competing human interventions
    • Relative weighting of management responses given observed changes
    • Reference points
    • Performance measures

2.2 Simple model of primary interactions in a food web

Assuming that one can delineate the geographical boundaries of the ecosystem of interest, the simplest model for the interactions between marine mammals or birds and a fishery is shown in Figure 2.1. In this case, the target fish are assumed to be prey for both the fishery and marine mammals or birds. The interactions can be either indirect, in which the fishery removes prey that the mammals or birds would otherwise take, or direct, in which there is incidental mortality of mammals or birds during fishing operations. This food web is one used implicitly by individuals when changes in marine mammals or birds are assumed to be caused by fishery activities.

2.3 Complexity of primary interactions

While Figure 2.1 may be a useful conceptual tool for framing interactions, it is an overly simplified management tool for deciding on the level of human intervention in an ecosystem. Potential complexities of the primary interactions can be divided into three broad categories:

- age-specific factors in the interactions between major species;

- temporal and spatial components to the interactions; and
- availability of target species.

These complexities are included in the food web in Figure 2.2.

2.3.1 Age-specific factors in the interactions between major species

The trophic level labeled "mammals and birds" makes no distinction between different life history stages, such as juveniles and adults. Both the direct and indirect effects of the fishery may differ between juveniles and adults, for a variety of reasons.

Similarly, once this trophic level is separated into adults and juveniles, effects on growth (especially the transition from juvenile to adult) and reproduction (the production of new juveniles) may be different.

2.3.2 Temporal and spatial components to interactions

The simple web in Figure 2.1 is based on the assumption that the fishery targets a single stock that is also the sole prey source for the marine mammals and birds. However, marine mammals and birds often have cosmopolitan diets; thus the trophic level occupied by "target fish" may also be occupied by other fish species that are competitors of the target species and prey for the mammals and birds.

In a similar way, the marine mammals and birds may themselves be prey for other marine organisms, such as toothed whales or sharks or marine diseases. These ideas are captured in Figure 2.2

2.3.3 Availability of target species

As indicated in MRAG Americas (2000), one should expect variation in ecosystems. Thus, the target species may be removed by the fishery (leading to interference competition with the marine mammals or birds), but it may also move in space relative to the location of the fishery and the marine mammals or birds. For example, in Monterey Bay, California, during El Nino years, krill move off-shore to cooler waters and their predators that are fishery targets (such as squid and anchovy) follow them, thus moving the fishery targets relative to the shore.

2.4 Environmental Effects on Primary Interactions

Although the enlarged food web in Figure 2.2 is more complex, it ignores environmental factors that affect the production of fish stocks. These may be biotic (e.g. the level of zooplankton, as described in Section 2.3.3, or primary production) or abiotic (e.g. different temperature regimes) factors that affect the fish stocks. Figure 2.3 captures these ideas.

2.5 The roles of ecological detection and adaptive management

Each of the food webs in Figures 2.1-2.3 can be viewed as a verbal model for the ecosystem and its interactions. If one were now confronted with the piece of information that marine mammals or birds in an ecosystem had declined, different hypotheses could be generated by these models.

We show some examples in Table 2.1, knowing that these are “nested” in the sense that more than one of them could apply.

Given a set of data concerning the decline of marine mammals, one view of the role of analysis is that its purpose is to confront each of these putative explanations of the decline with the data and allow the data to arbitrate between the different models. Hilborn and Mangel (1997) call this process ecological detection. Ecological detection recognizes that our understanding of the world will always be incomplete and that the goal should be to achieve the best understanding possible by working with multiple hypotheses.

In a similar manner, methods of adaptive management (Parma et al 1998) can be used to help direct human intervention (in this case fishing) in a way that one learns about the system and is thus able to better ascertain which of the competing models is the best representation of the situation. Perhaps the most important lesson from adaptive management is the crucial role played by variation in whatever controls are applied. Without such variation in control measures, at the end of a time period one will be unable to interpret the results of the control activities.

The notions of ecological detection and adaptive management recognize that we will never fully understand natural systems. However, ignorance and uncertainty are neither reasons for stopping all human intervention in such systems nor are they reasons for carrying on as usual. Rather, ignorance and uncertainty force us to act in ways such that intervention in systems will provide information about those systems and thus reduce our ignorance and uncertainty, but never eliminate them. And because ignorance and uncertainty can never be eliminated, we must proceed with caution while using human activity to develop an information base that will allow better understanding of what is happening in the ecosystem. As will be seen below, a key feature of this understanding is to have contrast in human intervention.

The verbal models described in Figures 2.1-2.3 can be converted into mathematical models of virtually any desired complexity. However, it is insufficient to have a model; the model also needs to be used in a manner that will maximize the insight and intuition obtained from it.

3 Developing and using models of fisheries effects

In this section, we use a number of simple models to illustrate the different predictions that arise from the verbal models in Table 2.1 and to ask "how much does the fishery retard recovery of the marine mammals".

3.1 An illustrative example

We begin with a model that illustrates an approach to the latter question.

Imagine a population of marine mammals that grows, in the absence of fishing for a target stock that it shares with humans, according to the dynamics

$$N(t+1) = N(t) + rN(t)\left(1-\left(\frac{N(t)}{K}\right)^{A}\right) \tag{1}$$

In this equation, N(t) is the population size in year t, r is the maximum per capita growth rate (set equal to 0.12 for the computations), K is the carrying capacity (set equal to 25000 for the computations), and A is a parameter used to characterize the density dependence of growth (A=2.4 is often used to characterize marine mammals).

Also assume that the population has dropped to 6.25% of carrying capacity and that fishing is known to decrease the maximum per capita growth rate (Mangel and Hofman (1999) discuss the situation in which carrying capacity has been reduced, as we do below) so that if the harvest on the target fish stock is h the dynamics of the population are now

$$N(t+1) = N(t) + (r-h)N(t)\left(1-\left(\frac{N(t)}{K}\right)^{A}\right) \tag{2}$$

We ask: how does the level of fishing activity affect the time that is required for the marine mammals to recovery to 36% of carrying capacity? The results are instructive for two reasons. First, even in the absence of fishing on the target stock, the marine mammal stock will take a considerable time to recover to a relatively low level vis-a-vis carrying capacity (Figure 3.1). In this case, the recovery time is 16 years in the absence of a fishery on the target stock. Hutchings (2000) recently documented a similar phenomenon in the recovery of marine fish stocks themselves – that many stocks showed little recovery within 15 years of the cessation of heavy fishing pressure.

Second, the relative recovery time, defined to be the recovery time in the presence of a fishery for the target stock divided by the recovery time in the absence of such a fishery, is a nonlinear function of the relative per capita growth rate, defined as (r-h)/r (Figure 3.2). Small levels of fishing have very different consequences than larger levels of fishing: a 10% reduction in per capita growth due to fishing increases the recovery time by 12.5%, a 20% reduction increases the recovery time by 25%, but a 40% reduction increases the recovery time by 62.5%. There is a strongly nonlinear relationship between harvest and recovery.

3.2 The relative importance of different factors on recovery rates of listed species

The food webs drawn in Figures 2.1-2.3 also show that different factors may be involved in consideration of the direct and indirect effects of fisheries on marine mammals and birds.

One way of viewing these is as a series of questions that can help frame the models:

- What factors influence mortality rates?
- What factors influence reproductive rates?
- What factors influence migration?
- Which factors can be manipulated through human intervention, such as through fishing controls?
- Which factors are most important for considering in a monitoring program and management procedure?

3.3 A more complicated example

We now elaborate the model described in Section 3.1, in light of the questions raised in Section 3.2 and some features from MRAG Americas (2000).

We assume that the population dynamics of the marine mammal or bird are given by

$$N(t+1) = N(t)\exp(-M_a-qE) + r\exp(-M_j)N(t)\{1-(N(t)/K)^A\} \tag{3}$$

where M_a and M_j are the natural moralities of the adult and juvenile marine mammals, q is the incidental mortality per unit of fishing effort, and E is fishing effort. The parameters r and A are interpreted as above, but now we allow K(t), which is analogous but not identical to carrying capacity (because of the mortality on N(t)) to be a function of time. We will also assume that observers on fishing vessels reduce the incidental mortality of marine mammals by 70%.

We assume that K(t) is determined by the abundance of forage fish F(t), which are less preferred by the marine mammals, and specialty fish S(t), which are more preferred by the marine mammals and which are a target for a fishery:

$$K(t) = aF(t) + bS(t) \tag{4}$$

where a and b are parameters that convert from biomass of fish stock to numbers of marine mammals. We assume that the forage fish and specialty fish compete with each other, the ecological dynamics of the two populations could be described by the set of coupled equations

$$\begin{aligned} S(t+1) &= S(t)e^{-M_s-\hat{q}E} + r_s S(t)\{1-\frac{S(t)+\alpha F(t)}{\bar{S}}\} \\ F(t+1) &= F(t)e^{-M_f} + r_f F(t)\{1-\frac{F(t)+\beta S(t)}{\bar{F}}\} \end{aligned} \tag{5}$$

.

where M_s, r_s, $\bar{S}$, and $\hat{q}$ are the natural mortality, maximum per capita growth rate, stock size at which there is no net reproduction, and catchability of the specialty fish and M_f, r_f, and . $\bar{F}$ are the analogous quantities for the forage wish. It is well known that such equations may have multiple possible steady states and that a perturbation (such as fishing) may move the system from the region of attraction of one steady state to another. The intensity of competition is measured by the competition coefficients α and β. We do not report a full suite of results here, but do note that the qualitative conclusions described above do not change at all with this complication. However, the quantitative results do change, because of the resulting competition between the forage and specialty fish.

Note that these equations assume a one-way interaction (the size of the fish stock affects the marine mammals, but not vice-versa) in the sense described in MRAG Americas (2000). We assume that there are spatially “replicate” units in which these dynamics apply; if such units are not available, then replication needs to be done temporally (discussed below).

The numerical solution of Eqns 3-5 in the absence of fishing (E=0) generates a steady state for the marine mammals. Given that this is the starting condition, we then allow three effects:

• Introduction of fishing. At t=0, fishing effort, switches from 0 to a constant value greater than 0.

• Environmental change. At time t_{regime}, a regime shift occurs and $\bar{S}$ and $\bar{F}$ are changed to new values $\kappa_e \bar{F}$ and $\kappa_e \bar{S}$, with $\kappa_e < 1.$

• Change in predator abundance. At time $t_{predators}$, an increase in either toothed whales or disease occurs, so that the mortality rates for juvenile and adult marine mammals becomes , with

A number $\kappa_j M_j$ and $\kappa_a M_a$ of κ_j and $\kappa_a > 1.$ important points emerge from formulation of the model:

- An unfished region is required, in order to establish a set of baseline data.
- The only way that it is possible to note the simultaneous increase in predation rates and decrease in fish carrying capacity is through monitoring fish stocks -- both forage and specialty -- in the unfished region.
- If there is an environmental carrying capacity and competition between the two fish stocks such that F(t) + S(t) is constrained, then stopping fishing activity may not return the stocks to their original levels.

In Figure 3.3, we show results (for parameter values shown in Table 3.1) that compare the specialty fish stock biomass and marine mammals at the onset of fishing and after a 20 year period in which no areas are set aside for baseline data and no observers are placed on fishing vessels to monitor incidental take of marine mammals.

In this case, the results are

Ecosystem Situation	Abundance	
	Specialty fish (mtons)	Mammals (individuals)
Start of fishing	2864	14039
End of a 20 year fishing period	1879	9647

Based on these data, one would conclude that the 34% drop in fish stock biomass lead to a 31% decline in the abundance of marine mammals. The conclusion would be that there is a 1:1 dependence of the marine mammals on the specialty fish and that the fishery caused the decline of mammals. As described in MRAG Americas (2000), because fishing effort is the most obvious and most controllable aspect of the system, there is a tendency to blame fisheries when such declines are observed.

Note, however, how the interpretations may change if a more holistic, ecosystem approach is taken. First consider the effect of baseline data, obtained by monitoring forage and specialty fish in an unfished region, on the interpretation of the results

Ecosystem Situation	Abundance		
	Forage Fish (mtons)	Specialty fish (mtons)	Mammals (individuals)
Start of the 20 year period	3280	2864	14039
End of the 20 year period	2623	1879	12289

We now see, by monitoring the forage fish that are not targets for a fishery, that an ecosystem change occurred. Assuming that the same changes effect both forage and specialty fish equally, we can now partition the decline in specialty fish (total amount 985 mtons) into an environmental component (481 mtons) and a component due to the fishery (504 mtons). Thus what would have, in the absence of appropriate monitoring, been a conclusion of a decline completely due to the effects of the fishery is now a conclusion that the decline is in part due to the fishery and in part due to environmental change.

As described in MRAG Americas (2000), one should expect change in ecosystems, and that not all of this change will be anthropogenic in origin. Without monitoring the non-target stock in a baseline region, one would not have picked up the observation of ecosystem change.

Second, we consider the effects of including observers on the fishing vessels. As described above, we assume that the presence of observers reduces the incidental mortality level by 70%, due to increased attention to marine mammal rescue in the fishing process. In such a case the data now are

Ecosystem Situation	Abundance		
	Forage Fish (mtons)	Specialty fish (mtons)	Mammals (individuals)
End of 20 year period with fishing	2713	1879	9647
End of 20 year period with fishing and observers	2713	1879	10070

These observations now allow one to partition the decline in marine mammals between incidental mortality in the fishery (423 individuals) and mortality due to declining food resources (3969 individuals). Much more can be done about reducing the former than the latter. There is no significance in the particular values of these numbers, but in the conceptual point that they make.

One may also ask about the effectiveness of different recovery plans. For example, in year 20, recognizing that marine mammal stocks have declined, the fishery might be completely closed. Alternatively, the fishery might continue, but with a reduced level of fishing effort (e.g. 60% or 30% of the previous value). One can then use the model to follow the recovery of the marine mammal stock. An example is shown in Figure 3.4. Three important observations emerge. First, even in the absence of any fishing effort, the stock may continue to decline before it begins a recovery (in this case, the nadir occurs in year 25) because of the lags created by the population dynamics. Second, some levels of fishing are compatible with the recovery of the mammals, although fishing will delay the recovery (in the case of fishing effort 30% of the original value, the nadir of the mammal population occurs year 29). Third, not all levels of fishing activity are consistent with a recovery.

The results shown in Figure 3.4 suggest that it is possible to use the model to predict the jeopardy that continued fishing activity will present to the recovery of marine mammals. To illustrate this use, we ran the model at relative levels of effort ranging from 0 (closed fishery) to 1 (fishing effort unchanged) and evaluated the change in marine mammal populations after 10 years and 20 years (Figure 3.5). Two points emerge from this figure. First, even if the fishery is completely closed, the marine mammal population dynamics are such that no recovery will be observed over a 10 year period (Figure 3.5a, relative effort =0). Second, on a longer time frame, there are levels of fishing effort that are consistent with the recovery of the marine mammal population (Figure 3.5b, values of change greater than 0). More complicated population models such as York (1994) or life history models with facultative reproduction (Clark and Mangel 2000) are not likely to change either of these conclusions, although the quantitative details may vary.

As described above, the model that we use assumes direct and indirect effects of the fishery, an environmental regime shift, and a shift in predator. One may ask about the recovery process if the decline of marine mammals is solely due to the fishery. The results (Figure 3.6) are both instructive and surprising. If the decline is solely due to the effects of fisheries, then the recovery will be quicker once fishing effort is reduced. For example, in this case, there is a positive change in marine mammal population size after 10 years even if fishing continues (Figure 3.6a). Furthermore, higher levels of fishing effort are allowable in this case than if the decline is caused by some features that cannot be affected through the control of human intervention. This result, while somewhat counter-intuitive on first glance makes perfect sense on further consideration. Furthermore, it emphasizes the importance of regions in which there is no fishing effort and sampling of both specialty and forage fish.

3.4 Observational uncertainty and statistical power

To be sure, the example of the previous section is still considerably simplified, especially because neither process nor observational uncertainty (Hilborn and Mangel 1997) are included in the models. However, including them will not change the main message that regions with different kinds of management actions are needed to develop the contrast necessary to interpret what is happening in the ecosystem.

Process and observation uncertainty mean that more data will be required to draw conclusions, and that the conclusions can only be drawn in a statistical context. One conclusion may be that short time series simply cannot provide enough contrast, so that one must then proceed cautiously.

4 Monitoring for effects of fishing

4.1 Introduction

The discussion in Sections 3 highlights the need to monitor different aspects of the predator-prey system to determine the role of fishing in causing changes to a marine mammal population. A carefully designed monitoring program can also be used to determine the extent to which fishing may need to be reduced to achieve recovery of populations, and to signal when changes to fishing controls may be required. We now develop a prototypical sequence in the design of monitoring and feedback management systems based on the results of modeling in Section 3.

Ideally, the scale and resources applied to a monitoring program are commensurate with the value of the fishery and the program provides the information necessary for making decisions that are "correct" within the acceptable bounds of making Type I and II statistical errors. In fisheries terms, these errors are translated, respectively, into those that cause a reduction in fishing when it was not justified (Type I) and those that cause environmental harm when fishing should have been more effectively controlled (Type II). This is discussed in MRAG Americas (2000) and need not be considered further here except that the precision of monitoring (replication) needs to be such that these errors are kept within acceptable bounds.

In Table 4.1 we elaborate the hypotheses posed in Table 2.1 to explain a decline in a marine mammal or bird population. This table will be used in the discussion below. It summarizes what would be considered in designing an experimental monitoring program to distinguish between the relative importance of fishing and environmental factors in causing declines in a marine mammal population.

4.2 Variables to monitor

The most important element of the monitoring program is to determine the measures of the environment that will lead to the most appropriate management action. That is, one must identify the variables of interest, the magnitude of change or difference in those variables that would warrant action and the temporal scale on which management decisions need to be made. For example, managers would ideally prefer to receive feedback on the scale of one to two years concerning how to manage fisheries given the depleted status of a marine mammal population, rather than obtaining feedback over a longer period, say 10 years. As indicated in Section 3, population abundance is unlikely to provide such information in that time frame, even in the absence of fishing. An increase in the example marine mammal species (Fig. 3.4) may not be observed for 10 years or more.

The various hypotheses suggest that, along with total abundance, changes in the target fish species should cause more immediate changes in per capita rates such as body growth (weight), reproduction and mortality of the marine mammals (Table 4.1). These measures could potentially be used to establish a monitoring program that will discriminate between the hypotheses as well as testing the effect of different harvest levels on the recovery of a marine mammal population.

To monitor incidental mortality of marine mammals in fishing operations, assuming land-based marine mammals have a high fidelity to a particular colony, a mark-recapture program could provide information on changes in mortality rates. Return rates from one year to the next could be monitored in conjunction with changes in the level of fishing effort in the associated foraging range of the marine mammal.

If fishing is altering the productivity of the marine mammal then a reduction of fishing may have a number of effects depending on the state of the target stock, the amount of effort available and the size of the marine mammal population. In a given year, if the biomass of the target species is greater than consumption by the predator plus the maximum catch of the fishery then no competition between the fishery and the marine mammal is likely to occur. If the target species is low in biomass in that year then the effects of competition should be evident. Such effects would be lower body mass and lower reproductive success. Mortality due to starvation may not necessarily occur in the first season. If competition were the primary cause of decline then evidence of competition would be expected in the early phase of the fishery when the carrying capacity of the ecosystem has been reduced but the concomitant decrease in the marine mammal population has not yet occurred. However, if the fishery is well advanced and its catches relatively stable, then the marine mammal population may have been reduced to the point that a new steady state population size has been reached.

A potentially confounding factor is whether the marine mammal is an obligate feeder on the target species. If not then it may not be affected if sufficient biomass of other species is available. Such prey switching could be detected through dietary analyses.

These considerations in Table 4.1 suggest that a monitoring program recording rates of reproduction, growth in body mass and dietary composition and mortality of tagged individuals could help discriminate between the alternative hypotheses in shorter time than simply monitoring abundance.

4.3 Spatial and temporal considerations

Discrimination between the hypotheses requires a configuration of experimental areas to take account of the spatial and temporal components of each of the hypotheses.

The first hypothesis concerns incidental mortality. This is contrasted by the hypothesis concerning the increase in predation on the marine mammal by toothed whales. If the fishery is a direct cause of mortality then the loss of tagged individuals should be greater from populations in the vicinity of fishing activities compared to those distant from fishing. This would be compared to the expectation that predation by toothed whales occurs across all populations. In the absence of knowledge on the latter, an experiment could be undertaken where mortality is monitored in colonies with the same fishing effort nearby. One could randomly divide the colonies into two groups, with one set subjected to no fishing and the other subjected to fishing at levels expected to cause an effect.

The hypotheses concerning the causes of starvation may require a complex set of spatial treatments. The potential for variable abundance of the target species implies that two levels of fishing would be required in an experiment to detect significant effects on the productivity of the marine mammal – zero and typically high levels of harvest. An additional extremely high level of harvest may be required for a short term experiment if there is no knowledge of how much harvest is thought to be required to cause competition in a given year with the existing population of marine mammals. These considerations may lead to unequal distribution of effort across monitoring areas to account for differences in availability of target species and/or abundance of marine mammals. These experimental regimes need not lead to mortality as they aim to detect changes in the productivity of individuals. Diet would be monitored in conjunction with body weight.

Ideally, changes in productivity of the marine mammal would be monitored over a number of years so that changes in production in areas closed to fishing could be used to judge whether changes in marine mammal populations are responding to overall changes in productivity in the system or simply changes arising from fishing.

The assessment of these hypotheses would be enhanced by monitoring other predators dependent on the target species as “control species”, as well as monitoring the overall productivity of forage species.

4.4 Experimental design

4.4.1 Replication

Per capita rates are usually extremely variable between individuals and between areas. In terms of the hypotheses in Table 2.1, the scale of interest is at the colony level rather than the individual. Thus, a replicate in this work is the average per capita rate within a colony. In terms of the three types of rates, sampling within a colony may not require many individuals to be monitored. Each year may require only one visit to the monitored colonies during the peak productivity period to estimate mortality over the previous year (monitoring tags), reproductive rate (number of pups in the colony compared to the number of females) and body size, which may be a suitable indicator of nutritional state if estimated at an appropriate time.

Changes in the spatial arrangement of production are expected from one year to the next. Such a scenario would require areas open and closed to fishing to be located reasonably close together to ensure that one area is not influenced more than another by changes in production. However, sometimes this cannot be avoided. Consequently, replication of the open and closed system is necessary to identify whether the effects of fishing are consistent across the entire geographic range of interest. These designs are commonly known as randomized block designs. The number of replicate blocks would need to be considered in light of the overall power of the monitoring program to provide information on the effects of fishing.

4.4.2 Independence of treatments

The assignment of areas to a treatment (i.e. open or closed to fishing) needs to be random. In addition, an area needs to be sufficiently large that the effects of fishing are constrained to that area i.e. other areas are independent from that area.

4.4.3 Magnitude of effects

Number of replicates etc. is constrained by the resources available to monitor but should be sufficient to detect effects of the magnitude considered important. It may be necessary to have a number of treatments of harvest level to try and circumscribe the curves detailed in Section 3.

4.5 Prospective feedback management procedures in ecosystem management

The design of the monitoring program should be such that the end of a specified period one can make a decision about how to proceed. Thus, at the outset one must specify the kind and level of monitoring necessary to provide the signals for adjusting fishing effort to cater for target recovery levels of the marine mammals, what harvest levels are appropriate, and the spatial configuration of the harvest.

To ensure that all colonies recover and that one obtains information about the status of the system, one may rotate fishing mortality through the system. That is, rather than having uniform effort across areas, one would have a series of open and closed areas that rotate, with some remaining closed all the time to provide baseline data

A target level of recovery needs to be determined along with the desirable rates of recovery to that level. The modeling in Section 3 provides the foundation for setting the targets. The second prescription required is the acceptable probability of not identifying whether the fishing regime and monitoring is causing the target rates of recovery to not being achieved (i.e. Type II error rates). Similarly, a probability of not identifying when fishing controls can be relaxed needs to be identified (i.e. Type I error rates). Given these, a monitoring program to determine the effects of fishing on a depleted marine mammal population can be designed along with specifying adjustments to fishing (decision rules) as information is derived from the monitoring program.

The next stage in the process is to extend the work in Section 3 to determine whether the monitoring program and the decision rules are likely to achieve the targets within the bounds of the acceptable Type I and II error rates. This prospective evaluation of the feedback system is described by MRAG Americas (2000) and provides an opportunity to test whether a monitoring program will signal appropriate courses of action, given uncertainties in the underlying ecology of the system and the causes of variation in the estimates of parameters obtained through the monitoring program.

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Tables and Figures

Table 2.1 Hypotheses about the cause of a decline in marine mammals or birds based on different food webs

Food Web	Primary Hypothesis
Figure 2.1	The decline is caused by incidental mortality in the course of fishing operations
Figure 2.1	The decline is caused by removal of target fish by the fishery
Figure 2.2	The decline is caused by an increase in the toothed whales or the prevalence of marine disease
Figure 2.2	The decline is caused by a shift in the mixture of target fish and other fish, which provide different levels of nurtrients to the mammals and birds
Figure 2.3	The decline is caused by a shift in the distribution or abundance of zooplankton, thus affecting the resource base for the fish
Figure 2.3	The decline is caused by a shift in abiotic components, either temporall or spatially, that affect the distribution of fish stocks and their accessibility to marine mammals and birds.

Table 3.1 Parameters Used for Numerical Solution of the More Complicated Model

Mammal Parameters	M_a	0.05
	M_j	0.15
	r	0.12
	$\underline{A}$	2.4
Fish Parameters	$\bar{F}$	8000
	$\bar{S}$	10000
	b	5
	a	2
	M_s	0.3
	r_s	0.4
	M_f	0.3
	r_f	0.5
	α	0.2
	β	0.2
Operational parameters	q	0.05
	$\hat{q}$	0.2
	E	0.2
Ecosystem change parameters	t_{regime}	7
	$t_{predators}$	9
	κ_e	0.8
	κ_a	1.1

Table 4.1: Summary of hypotheses as to causes of declines in marine mammals or birds (Table 2.1), the effect those causes have on individuals, the role of the environment in driving those changes, variables of the marine mammals and birds that would need to be monitored in addition to abundance and the expectation of how those variables would alter if fishing was reduced.

Hypothesis	Immediate effect on individual marine mammals or birds	Environmental driver (other than target species being reduced)	Variables to measure (in addition to abundance)	Expectation given a reduction in fishing (including temporal scale)
The decline is caused by incidental mortality in the course of fishing operations	Death	None	Age-specific mortality	Mortality rate declines (immediately)
The decline is caused by removal of target fish by the fishery	Starvation	None	Body weight Reproduction Age-specific mortality	Body weight increases (one year) Reproduction increases (two years) Mortality rate declines (one to two years)
The decline is caused by an increase in toothed whales	Death	Production – none Toothed whales – increased	Age-specific mortality	No change
The decline is caused by the prevalence of marine disease	Ill health	Production – None Prevalence of disease – increased	Health Body weight Reproduction Age-specific mortality	No change
The decline is caused by a shift in the mixture of target fish and other fish, which provide different levels of nutrients to the mammals and birds	Starvation	Non-target fish – increase	Body weight Reproduction Age-specific mortality	No change
The decline is caused by a shift in the distribution or abundance of zooplankton, thus affecting the resource base for the fish	Starvation	Production – decrease	Body weight Reproduction Age-specific mortality	No change
The decline is caused by a shift in abiotic components, either temporally or spatially, that affect the distribution of fish stocks and their accessibility to marine mammals and birds.	Starvation	Production – displaced from foraging areas	Body weight Reproduction Age-specific mortality	No change

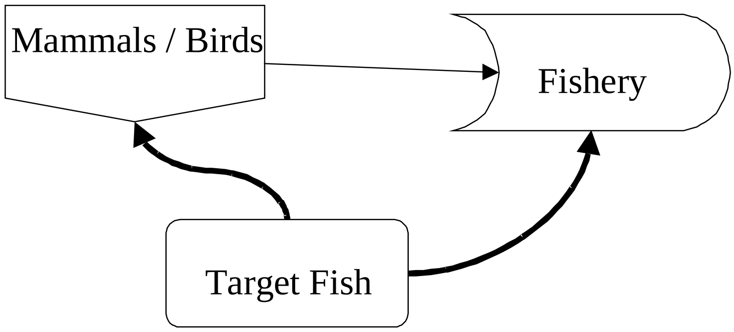


Figure 2.1 The simplest model for the interaction between marine mammals and birds and a fishery. In this case, the target fish are assumed to be prey for both the fishery and marine mammals or birds. The interactions can be either indirect, in which the fishery removes prey that the mammals or birds would otherwise take, or direct, in which there is incidental mortality of mammals or birds during fishing operations.

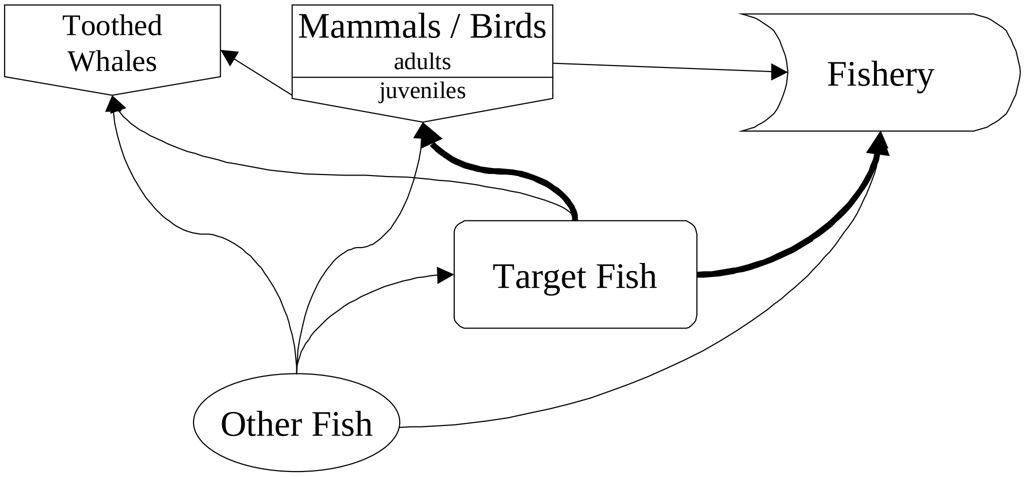


Figure 2.2 An elaboration of the simplest food web to account for age-specific factors in the interactions between major species, temporal and spatial aspects of the interactions, and availability of target species.

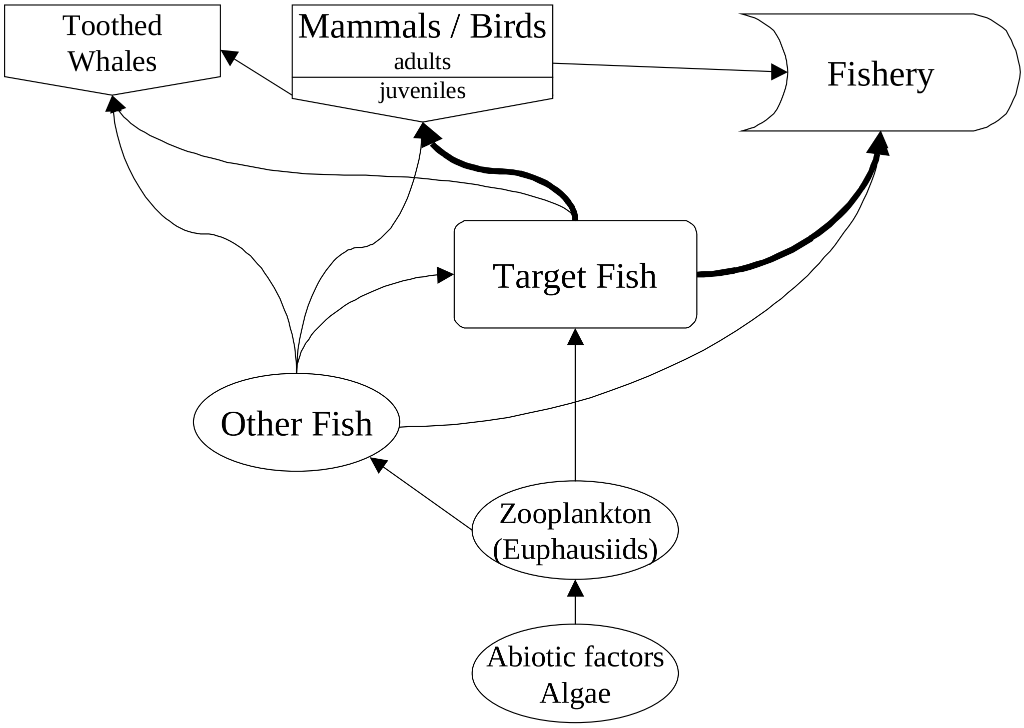


Figure 2.3 A food web that includes environmental factors.

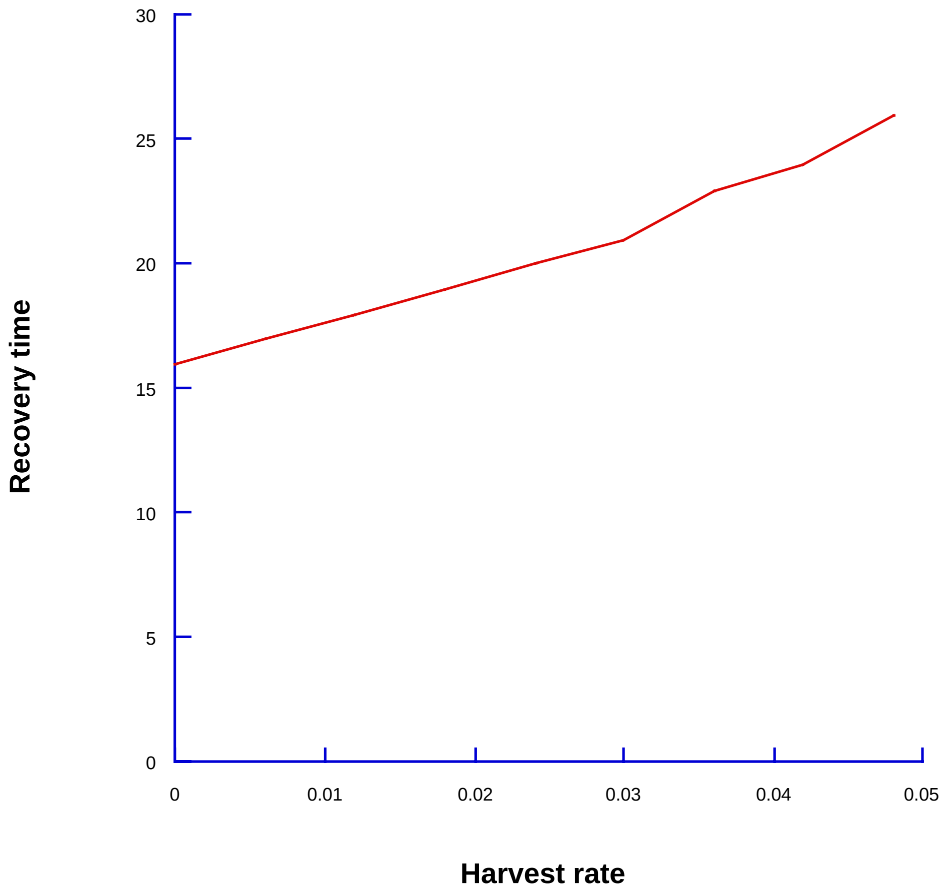


Figure 3.1 Time for a depleted marine mammal stock at about 6% of carrying capacity to recover to 36% of carrying capacity as a function of harvest rate on the target fish stock that the marine mammal shares with the fishery. A harvest rate of 0 means that the fishery is completely shut down and that the marine mammal stock grows at its maximum per capita growth rate. A harvest rate of 0.048 corresponds to a 40% reduction in the maximum per capita growth rate of the mammal population, due to fishing.

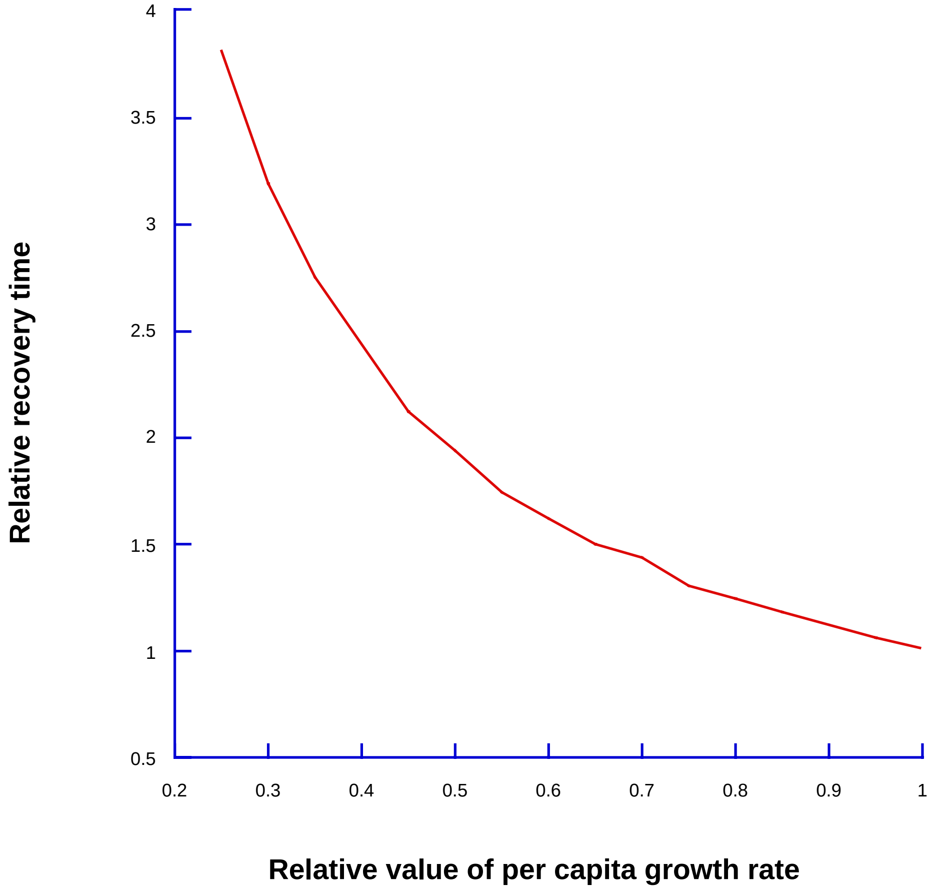
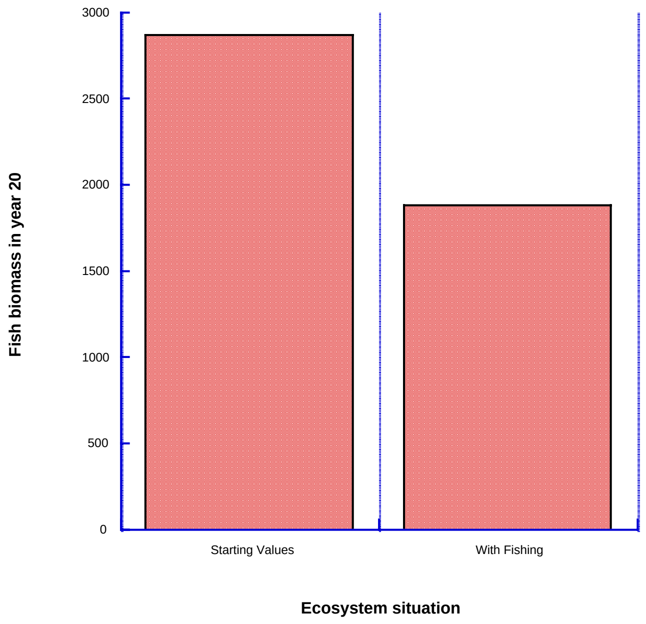


Figure 3.2 The relative recovery time (recovery time in the presence of a fishery divided by that in the absence of a fishery) as a function of relative per capita growth rate (r-h)/r for the data shown in Figure 3.1

(a)



(b)

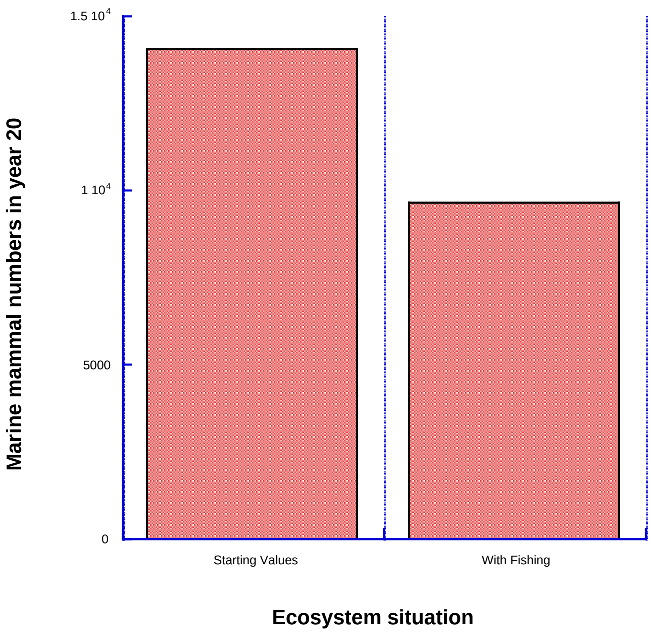


Figure 3.3 Model predictions for fish stock biomass (panel a) and numbers of marine mammals at the end of a 20 year fishing period where there is no baseline (unfished) region, no monitoring of incidental take, and no monitoring of forage fish

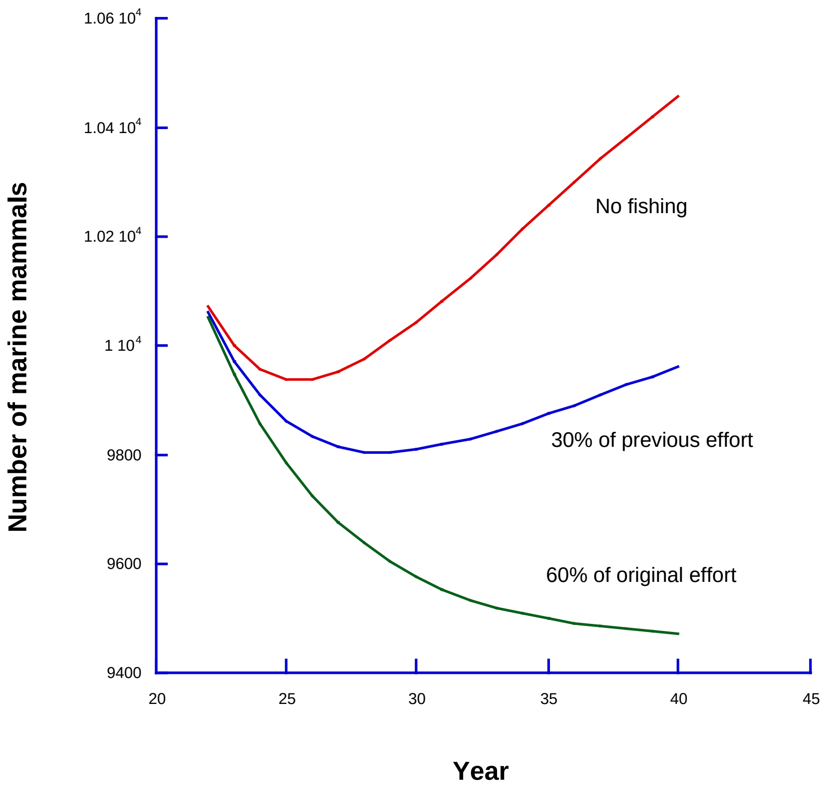


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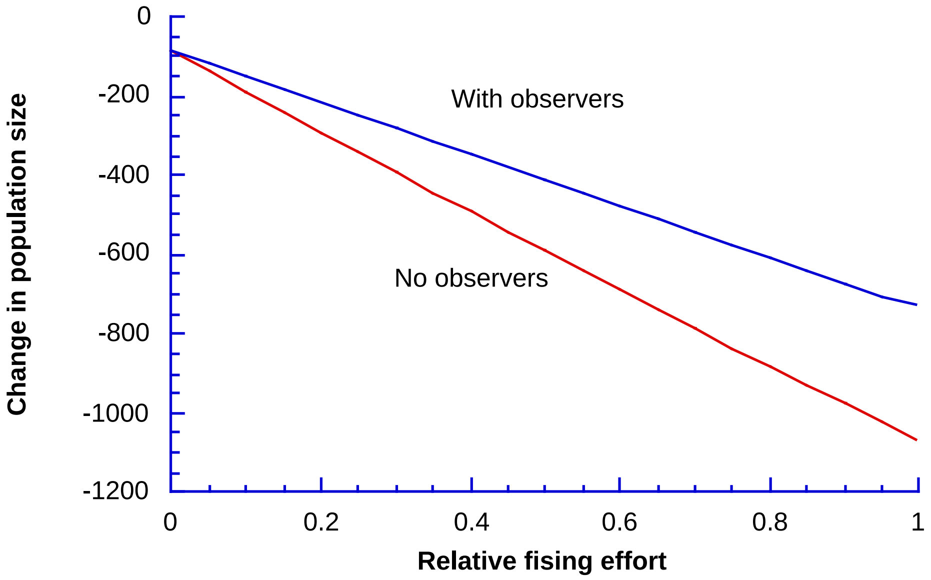
Figure 3.4 Recovery of the marine mammals between years 21 and 40 given that the fishery is completely closed (no fishing) or that fishing effort is reduced to 30% or 60% of its previous value.

(a)



(b)

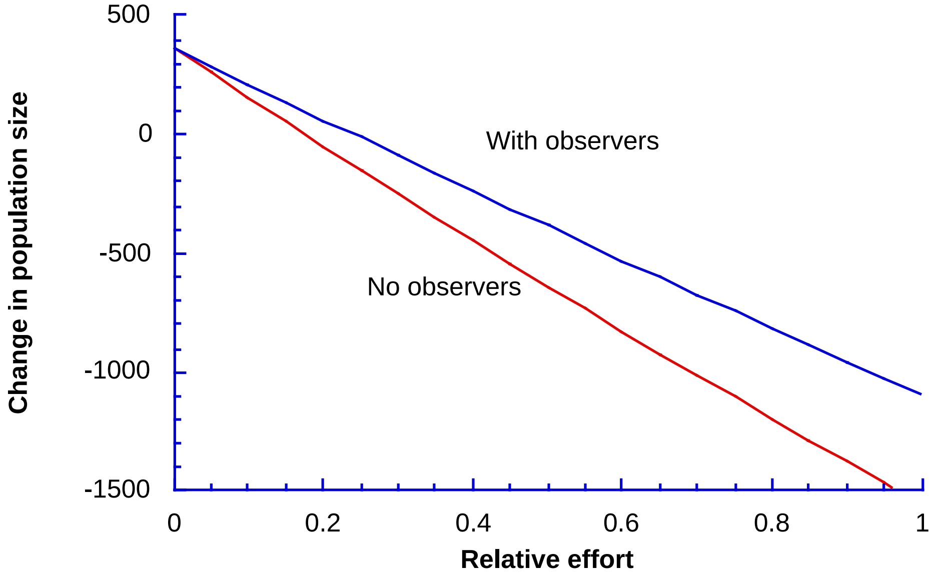


Figure 3.5 The change in marine mammal populations after 10 years (panel a) or 20 years (panel b) of regulation in which relative fishing effort varies between 0 (fishery closed) and 1 (no change in fishing effort).

(a)

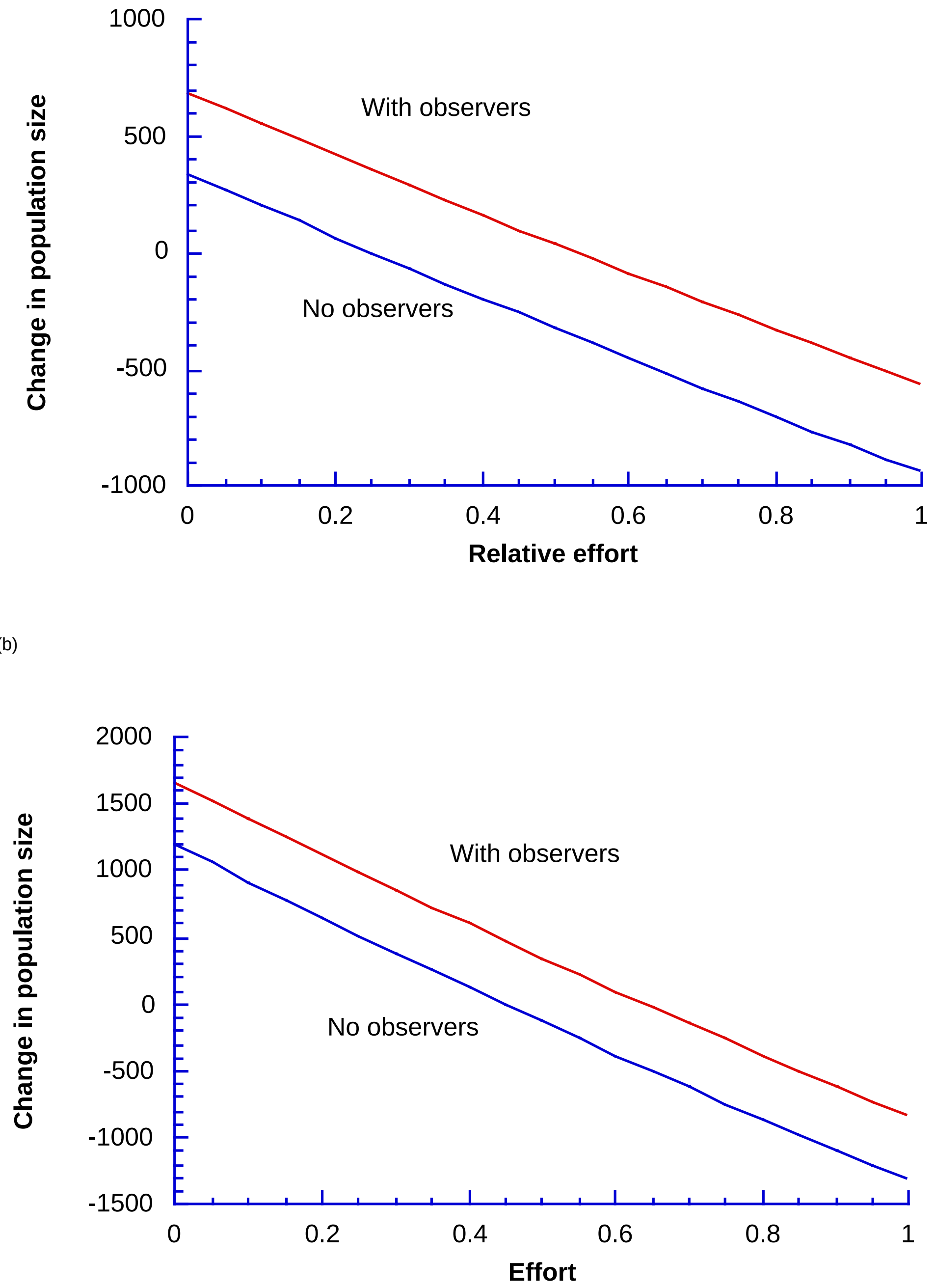


Figure 3.6 The same results as in Figure 3.5, but assuming that the decline in marine mammals is due solely to fishing (i.e., no regime shift and no change in level of predators).